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Optimal energy consumption model in transport

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Abstract

Transport is one of the most important components of infrastructure so far as the growth process of an economy is concerned. On the other hand a convergence of growing demand, resource constraints, and environmental imperatives will reshape our energy system. The future of production and consumption of the energy carriers and their correct and appropriate application in different sectors are of paramount importance. With a view to this and using a linear programming model, optimal allocation of energy resources to different sectors is discussed here. Meanwhile, political, economic, and environmental objectives are taken into consideration. To do so, the data related to 40 recent years are used for predicting energy demand in different consumption sectors and studying validity of model. In addition, allocation of oil and gas resources to different consumption sectors during 2013-2024 is discussed with respect to implementation of the targeted subsidies plan in Iran. The results of the present research provide programmers and decision-makers with appropriate approaches to offer a suitable programming on optimal allocation of energy resources.

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Keywords: Transportation; Optimal allocation; Oil; Natural gas

1. Introduction

Energy is of the factors used in most economic activities. National security of most countries depends on a reliable access to energy. Therefore, the future of production and consumption of the energy carriers and their optimal application are of paramount importance. Major part of the consuming energy in world is provided from fossil fuels, gas, and oil. With respect to the restrictions to increase crude oil and natural gas production, the ever-increasing consumption of oil and gas products and future generations' ownership of natural resources, necessity of optimization in supply and demand sectors of oil and gas are inevitable facts [1]. In addition global warming within recent decades has caused unpredictable problems for human life. One of the major factors of global warming is emission of greenhouse gases in atmosphere

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due to human activities. All the issues and problems mentioned above have made confrontation with the destructive effects of human activities in environment become one of the major global concerns, as finding solutions to reduce or remove these losses would be a major part of the global discussions [2]. With respect to the abovementioned items, the present research designed a suitable mathematical model for optimal allocation of oil and gas in transportation field with regard to different objectives to maintain political security and energy security, to preserve economic interests, and to reduce emission of greenhouse gases.

2. Method

Many mathematical models have been proposed for optimal allocation of energy resources so far. Some present energy models, such as MESSAGE (Model for Energy Supply System Alternatives and their General Environmental Impacts) and TIMES (The Integrated MARKAL-EFOM System) discuss energy system optimization [3]. Using operations research techniques, researchers also studied optimal allocation of energy resources in different consumption sectors. In this section mathematical model for oil and natural gas allocation to transportation section is designed here. Variables, parameters, objective function, and constraints of the model are as follows.

2.1. Objective functions

The objective functions with political, economic, and environmental approaches are as follows:

$$Min \;\; z_1(T) = I_o(T) + I_b(T) + I_g(T) + I_e(T) \tag{1}$$

$$\begin{aligned} Max \;\; z_2(T) &= P_c(T) \times \mathrm{E_c}(T) + P_o(T)(E_o(T) - I_o(T) - h_o(T)(k_{ot}(T)) + P_b(T)(E_b(T) - I_b(T) - h_o(T)(k_{bt}(T)) \\ &+ P_g(T)(E_g(T) - I_g(T) - h_g(T)(k_{gt}(T)) + P_e(T)(E_e(T) - I_e(T) - h_e(T)(k_{et}(T)) \end{aligned} \tag{2}$$

$$Min \;\; z_3(T) = m_{ot} k_{ot}(T) + m_{gt} k_{gt}(T) \tag{3}$$

2.2. Model restrictions

The model restrictions include balance constraints and demand constraints and upper and lower limits of variables follows:

$$\begin{aligned} &c(T) = E_c(T) + k_{co}(T) \,,\; o(T) = k_{co}(T) \times f_o(T) \,,\; o(T) + I_o(T) + I_b(T) = E_o(T) + k_{ot}(T) + k_{oo}(T) \\ &k_{ot}(T) \times p_{bt}(T) = o(T) \times z_b(T) + I_b(T) - E_b(T) \,,\; g(T) = R(T) \times f_g(T) \,,\; g(T) + I_g(T) = E_g(T) + k_{gt}(T) + k_{go}(T) \\ &sp(T) + k_{fp}(T) \times f_p(T) = e_1(T) \,,\; sp(T) = e_1(T) \times P_{sp}(T) \,,\; e(T) = e_1(T) \times w(T) \,,\; e(T) + I_e(T) = E_e(T) + k_{et}(T) + k_{eo}(T) \end{aligned} \tag{4}$$

$$k_{ot}(T) + k_{gt}(T) + k_{et}(T) \geq D_t(T) \,,\; k_{ot}(T) \geq D_{ot}(T) \tag{5}$$

$$k_{gt}(T-1) \leq k_{gt}(T) \leq U_{gt}(T) \,,\; k_{et}(T-1) \leq k_{et}(T) \leq U_{et}(T) \,,\; E_c(T-1) \leq E_c(T) \,,\; E_g(T-1) \leq E_g(T) \tag{6}$$

We have many variables and parameters which are related to year T that $k_{co}(T)$ is crude oil converted into oil products, $E_c(T)$, $E_o(T)$, $E_b(T)$ are export of crude oil, oil products and gasoline, $I_o(T)$, $I_b(T)$ are oil products import (apart from gasoline) and gasoline import, $k_{ot}(T)$, $k_{gt}(T)$ are oil products and natural gas allocated to transportation sector, $k_{oo}(T)$, $k_{go}(T)$ are oil products, gas allocated to non-transportation sectors, $E_g(T)$, $I_g(T)$ are natural gas export and import, $E_e(T)$, $I_e(T)$ are export and import of electricity, $k_{et}(T)$, $k_{eo}(T)$ are electricity allocated to transportation and non sectors, $k_{fp}(T)$ is fuel (oil and natural gas products) allocated to power plants, $c(T)$ is crude oil production, $o(T)$, $R(T)$, $g(T)$ are production of oil products, rich natural gas and light gas, $e_1(T)$ is generation of electricity, $e(T)$ is electricity after deducting transfer and distribution losses, $D_t(T)$ is energy demand of transportation sector, $D_{ot}(T)$, $D_{gt}(T)$, $D_{et}(T)$ are oil products, gas and electricity demand of transportation, $f_o(T)$, $f_g(T)$, $f_p(T)$ are efficiency of oil refineries, gas refineries and power plants, $w(T)$ is losses of transfer and distribution of electricity, (percent) $h_o(T)$, $h_g(T)$, $h_e(T)$ are subsidy on oil products, gas and electricity (percent) $p_c(T)$ is real price of crude oil, (dollars per barrel) $p_g(T)$, $p_b(T)$, $p_o(T)$, $p_e(T)$ are real price of gas, gasoline, other oil products and electricity, m_{ot}, m_{gt} are mean of emission of greenhouse gases produced by consuming oil products and natural gas in transportation sector (million tons of carbon dioxide equivalent to MBOE) $U_{gt}(T)$ is high level of natural gas consumption in transportation sector, $z_b(T)$ is gasoline extraction coefficient from oil refineries of the country, $p_{bt}(T)$ is gasoline used in transportation sector and $p_{sp}(T)$ is electricity supplied by renewable energies.

3. Model results for Iran

Data related to the model were collected from a vast number of different sources such as International Institute for Energy, Iran Energy Efficiency Organization [4], National Iranian Oil Company (NIOC), and Institute for International Energy Studies (IIES) [5], Iranian Fuel Conservation Company (IFCO) [6, 7] and National Iranian Oil Refining & Distribution Company (NIORDC) [8].

Following assumptions were considered to solve the model with respect to the information collected from the relevant organizations. During the implementation of the targeted subsidies plan, price of oil products and electricity would reach 90 percent of the world price and price of natural gas would reach 75 of the world price until the end of the fifth development plan. Price of oil products and electricity during 4 stages would reach 50, 70, 80 and 90 percent of the world price, respectively. Price of natural gas would reach 50, 60, 70, and 75 percent of the world price. Greenhouse gases include carbon dioxide, methane, and nitrous oxide. Carbon dioxide equivalent was considered in calculating emission of methane and nitrous oxide, as the effective index of the greenhouse gases is Global Warming Potentials. Global warming potentials of methane and nitrous oxide within 100 years are respectively 23 and 300 times bigger than the global warming potentials of carbon dioxide [9]. Energy demand, including total energy demand and oil products, natural gas and electricity demand were predicted using hierarchical neural networks methods, hierarchical fuzzy linear regression [10] and the data related to 40 recent years. Moreover, the appropriate model was selected and energy demand in the coming years (Table 1) was predicted with respect to the percentage of mean absolute error. It should be noted that neural networks method was a better method for predicting energy consumption in different sectors, as it had fewer test data [11].

Table 1. Prediction of energy consumption in transportation sector (MBOE)

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Energy	382	398	415	431	448	464	480	496	511	527	543	558
Oil Products	339	349	358	367	376	385	393	402	410	418	426	434

The results of the model are shown by Figure 1 using the data, information, and the assumptions related to 2013-2024. The model is solved using optimization modeling software.

As it is noticed, transportation sector is one the major consumers of oil products. Natural oil consumption in this sector is not developing much due to limitation of the required infrastructures. Moreover, a large amount of crude oil is allocated to export.

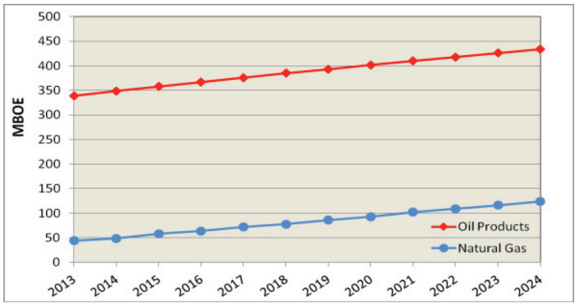

Fig. 1. Optimal allocation of oil and natural gas during 2013-2024

To examine the validity of the proposed model, its results were compared with the ones of the real performance in 2011. The results show the average improvement of 11.8% for the objective function. Therefore, the proposed model has the necessary validity.

4. Conclusion

In future years total fuel demand in all transport modes will increase by 30%-80% over Current situation levels. With this view the present study specified optimal allocation of energy resources to transportation sector in Iran during 2013-2024 with respect to the political, economic, and environmental objectives and state's future programs. A multi-objective goal-programming model was used for modeling. Model's limitations included balance constraints, demand constraints, and upper and lower limits of variables. The results of the present research can be applied for optimal allocation of oil and natural gas to the relevant sector and future planning.

It is proposed to design and implement energy optimal allocation model in a seasonal manner. It is also proposed to consider subdivisions of the sector under study in consumption field individually. (For instance, light and heavy vehicles are separated in transportation sector).

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